5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

5.1 STANDARD PRACTICE FOR REGIONAL GROUNDWATER MODELS

A groundwater model cannot simulate all of the complexities of a natural groundwater system, such as the presence of each individual fracture in a carbonate aquifer or the heterogeneities of the surficial glacial deposits. A model is a simplified mathematical representation of the natural system. On average across the entire study area, a groundwater model will provide a reasonable representation of groundwater flow. To check the validity of the model, the results of the model are compared with known information about the natural system, such as groundwater levels, inflows, outflows, and flowpaths.

Calibration of a groundwater model is performed by modifying the model input parameters such as hydraulic conductivity and recharge. The input parameters are adjusted within reasonable limits until the model results match recorded groundwater measurements as closely as possible. The accuracy of the calibrated model depends on the number of locations that groundwater measurements have been recorded, the length of time the measurements have been recorded at each location, and the distribution of the groundwater measurements across the modeled area. The accuracy of the calibration is generally assessed by determining the mean error. A positive mean error indicates that the model has overestimated heads, while a negative mean error indicates the opposite. The mean error could be near zero and still have considerable errors in the model. For example, if four (4) points have residual heads of -15 ft, -10 ft, +14 ft, and +11 ft, then the mean error would be near zero (0). However, this indicates that the model overestimated and underestimated the heads equally. Thus, several additional values are used to judge the model calibration: the mean absolute error, root mean square of the errors (RMSE), and the sum of residuals squared. The equations used are indicated as follows:

$$\text{Mean error} = [\Delta\,(M\text{-}S)]/N$$
$$\text{Mean absolute error} = [\Delta|M\text{-}S|]/N$$
$$\text{RMSE} = [(\Delta\,(M\text{-}S)^2)/N]^{1/2}$$
$$\text{Sum of Residuals Squared} = \Delta\,(M\text{-}S)^2$$

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

"M" is the measured groundwater level, "S" is the groundwater level calculated by the model, and "N" is the number of groundwater level measurements. The goal of the calibration process is to determine the set of model input parameters that minimizes these values.

Groundwater models can be calibrated to groundwater measurements using different sets of model input parameters. Generally, regional models that cover large areas and have multiple aquifer layers represented may be calibrated by several different methodologies and still have the same accuracy. For this model, considering the hydraulic conductivities, the recharge rates, and the stream parameters, there are nearly 150 parameters that can be adjusted to achieve calibration. Greater accuracy occurs by having sufficient historical groundwater measurements to be able to calibrate the model over a wide range of hydrologic conditions. Sufficient historical data include field measurements of hydraulic conductivity from aquifer tests in the area, recharge rates from precipitation, and discharge rates to streams.

5.2 FIELD MEASUREMENTS AND PUBLISHED GROUNDWATER LEVELS

During the development of the conceptual model, Black & Veatch contacted the Indiana Department of Natural Resources (IDNR), Indianapolis Water, Veolia Water, and Mundell and Associates to obtain historical data that has been collected for the surficial and carbonate aquifers in the Indianapolis area. Groundwater levels for the various aquifers and estimates of aquifer hydraulic conductivity across the study area are important for calibrating the model. Due to funding issues, IDNR no longer records groundwater levels from monitoring wells in the area (personal correspondence with IDNR, 2006). Most of the available data has been collected for the surficial aquifer while little data was available for the deep carbonate aquifer. IDNR published a potentiometric surface contour map across Marion County for the carbonate aquifer (Herring, 1976), but it is unknown the data that were used to develop this contour map. The IDNR contour map of the carbonate aquifer showed data that are 5 to 20 feet lower than recent measurements taken from the Phase 1A Geotechnical Program piezometers. Therefore, the model calibration is based on the recent data collected from the Phase 1A piezometers (Black & Veatch, 2006). The

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

decision to use the Phase 1A Geotechnical Program piezometer data for model calibration was jointly decided by the project stakeholders at the workshop on October 19, 2006. Table 5.1 presents the average groundwater levels measured from these monitoring wells that were used for calibration of the model in November 2006. The approximate locations of the six (6) piezometers are shown in Figure 5.1. The measurements collected since June 2006 and the surveyed locations of the monitoring wells are provided in Appendix A.

Table 5.1 Potentiometric Water Surface Elevations Measured for the Carbonate Aquifer

Phase 1A Monitoring Well ID	Average Elevation (6/30/2006 – 11/10/2006) (feet)
B-1	667.51
B-3	668.66
B-6	673.51
B-10	674.02
B-15	692.64
B-17	699.61

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

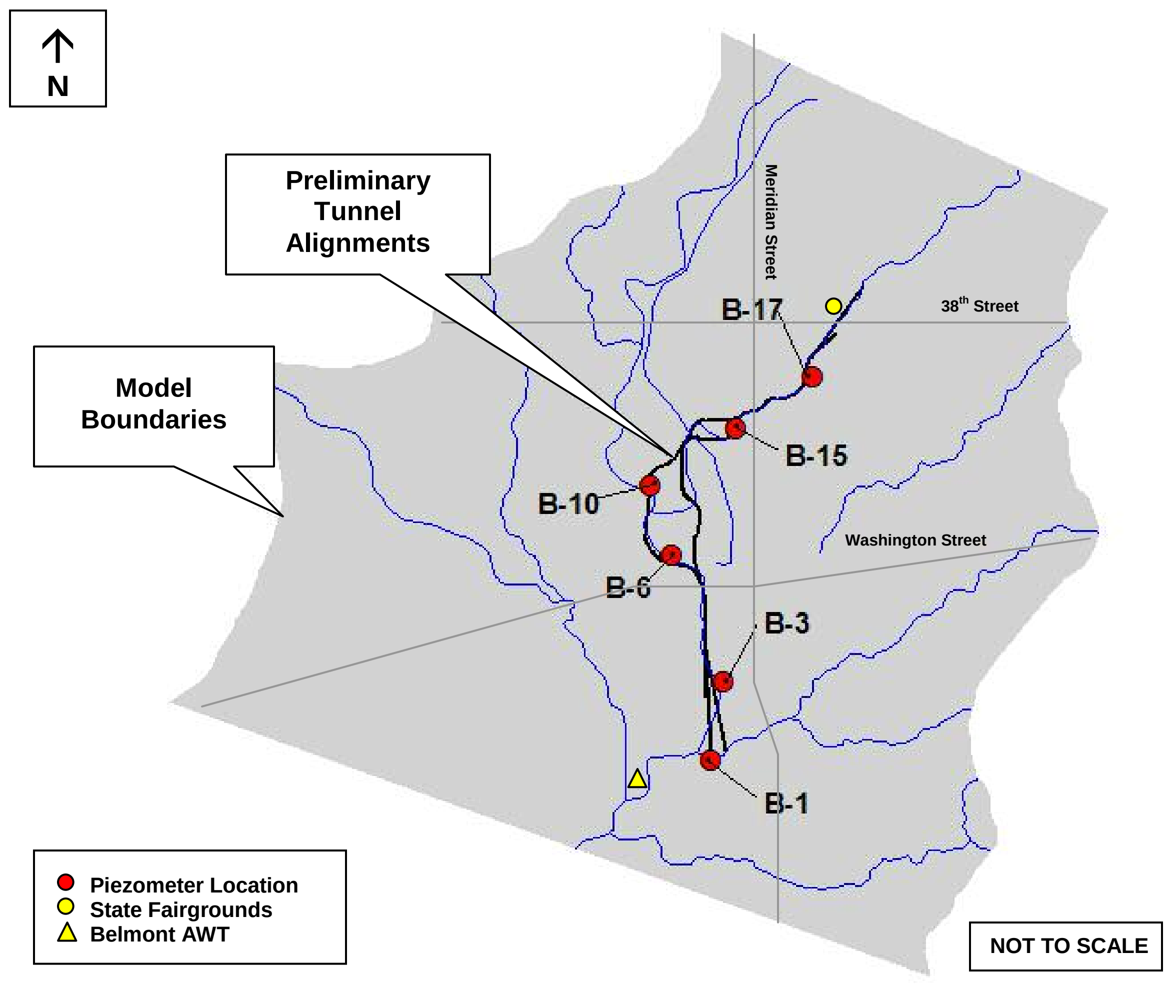

Figure 5.1 Phase 1A Piezometer Locations for Carbonate Aquifer

For the surficial aquifer, IDNR groundwater table contours from Year 2002 were used as a basis for calibration. This data is relatively current, and it is assumed that IDNR had a significant number of data points for the surficial aquifer to create these contours. In addition, data were obtained from IDNR for three (3) monitoring wells from the late 1980s to the late 1990s. These monitoring well locations are shown on Figure 5.2, and the average measured groundwater elevations for these wells are provided in Table 5.2.

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

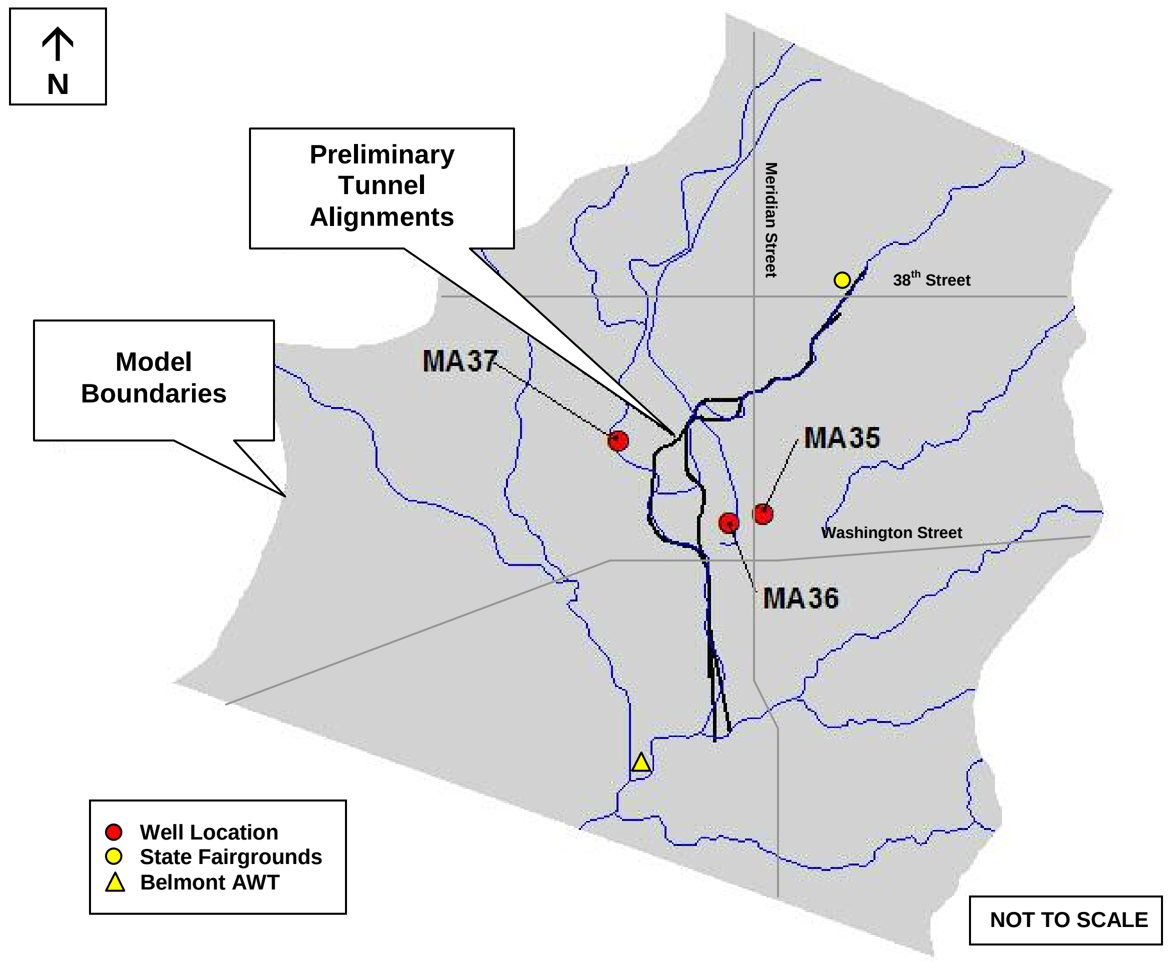

Figure 5.2 IDNR Monitoring Well Locations for Surficial Aquifer

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

Table 5.2
Groundwater Elevations for Surficial Aquifer
(average IDNR measurements taken in the 1980s and 1990s)

Monitoring Well	Average Elevation (ft)
MA35	685.60
MA36	680.06
MA37	682.98

Based on the available data, Table 5.3 shows the average differences in groundwater elevations between the surficial aquifer and the carbonate aquifer at the locations of the Phase 1A piezometers.

Table 5.3
Differences in Groundwater Levels

Phase 1A Piezometer Location	Difference in Groundwater Levels (ft) (surficial level minus carbonate level)
B-1	7.5
B-3	6.3
B-6	9.5
B-10	19.0
B-15	5.4
B-17	0.5

The groundwater levels in the surficial aquifer based on IDNR's 2002 contours are an average of approximately eight (8) feet higher than the groundwater measurements for the carbonate aquifer. Additional piezometers are recommended in future project phases to confirm the accuracy of this difference. It is important to verify the accuracy of the groundwater elevations for estimating the hydraulic conductivities, calibrating the model, and estimating the effect the tunnel may have on the regional groundwater levels.

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

5.3 CALIBRATION PROCEDURE

The calibration procedure for a groundwater model typically includes a three (3) step process. First, a steady-state model is calibrated to measured groundwater levels for a time period that the aquifer is believed to have reached equilibrium or normal conditions. Second, the resulting aquifer parameters obtained from the steady-state calibration are further refined using a transient model calibrated to a series of measured groundwater levels over a period of time. Lastly, the final parameters obtained from the transient model calibration are reapplied to the original steady-state model to assure the steady-state calibration is valid.

Since long-term carbonate aquifer groundwater measurement data is not available, a transient model calibration was not possible for this evaluation. The lack of long-term historical groundwater data is a common issue in groundwater modeling, and has previously been an issue within the study area for the alluvial groundwater model developed along the White River in the 1990s (ATEC, 1995). As several years of carbonate aquifer groundwater data become available from the network of monitoring wells installed along the proposed tunnel alignment, a transient model calibration may be beneficial in the future.

For this evaluation, the steady-state model calibration was performed using the average groundwater levels measured from the six (6) Phase 1A Geotechnical Program carbonate aquifer piezometers, three (3) IDNR surficial aquifer monitoring wells, and IDNR surficial aquifer groundwater contours. The following parameters were reasonably adjusted to achieve calibration:

- Horizontal hydraulic conductivities
- Vertical hydraulic conductivities
- Groundwater recharge rates
- Streambed conductance values

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

5.4 RESULTS OF CALIBRATION

The results of the model calibration are shown in Table 5.4, and discussed in this section.

Table 5.4
Groundwater Model Calibration Results

Observation Point	Aquifer	Source of Measured Elevation	Measured Elevation (feet)	Model Calculated Elevation (feet)	Residual (feet)
MA35	surficial	IDNR field measurements, 1990s	685.6	685.4	-0.2
MA36	surficial	IDNR field measurements, 1990s	680.1	681.8	1.8
MA37	surficial	IDNR field measurements, 1990s	683.0	685.9	2.9
idnr02c	surficial	IDNR estimated regional contours, 2002	725.0	728.3	3.3
idnr02d	surficial	IDNR estimated regional contours, 2002	725.0	722.5	-2.5
idnr02i	surficial	IDNR estimated regional contours, 2002	725.0	729.2	4.2
idnr02n	surficial	IDNR estimated regional contours, 2002	700.0	704.9	4.9
idnr02m	surficial	IDNR estimated regional contours, 2002	700.0	704.8	4.8
idnr02l	surficial	IDNR estimated regional contours, 2002	700.0	697.3	-2.7
idnr02k	surficial	IDNR estimated regional contours, 2002	700.0	694.2	-5.8
idnr02j	surficial	IDNR estimated regional contours, 2002	725.0	722.6	-2.4
idnr02g	surficial	IDNR estimated regional contours, 2002	700.0	701.4	1.4
idnr02f	surficial	IDNR estimated regional contours, 2002	675.0	673.5	-1.5
idnr02e	surficial	IDNR estimated regional contours, 2002	675.0	679.5	4.5
idnr02a	surficial	IDNR estimated regional contours, 2002	725.0	724.1	-0.9
idnr02o	surficial	IDNR estimated regional contours, 2002	700.0	706.5	6.5

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

Table 5.4 cont.
Groundwater Model Calibration Results

Observation Point	Aquifer	Source of Measured Elevation	Measured Elevation (feet)	Model Calculated Elevation (feet)	Residual (feet)
idnr02p	surficial	IDNR estimated regional contours, 2002	675.0	671.9	-3.1
B-1	shallow carbonate	Phase 1A boring measurements, 2006	667.5	671.9	4.4
B-3	shallow carbonate	Phase 1A boring measurements, 2006	668.7	670.1	1.4
B-6	shallow carbonate	Phase 1A boring measurements, 2006	673.5	678.6	5.1
B-10	shallow carbonate	Phase 1A boring measurements, 2006	674.0	678.6	4.6
B-15	shallow carbonate	Phase 1A boring measurements, 2006	692.7	695.5	2.8
B-17	shallow carbonate	Phase 1A boring measurements, 2006	699.6	702.7	3.1

The mean error, mean absolute error, and root mean square error of the calibration are as follows:

<u>Surficial Aquifer (17 points)</u>
Mean error = 0.98 ft
Mean absolute error = 3.14 ft
Root mean square error = 3.58 ft

<u>Carbonate Aquifer (6 points)</u>
Mean error = 3.58 ft
Mean absolute error = 3.58 ft
Root mean square error = 3.77 ft

The calibration charts are shown for the two (2) aquifers in Figures 5.3 and 5.4. The 45-degree line shown on these charts indicates the ideal match between measured and calculated groundwater elevations, and the points indicate the results of the calibration. For the surficial aquifer, there are about the same number of points above the 45-degree line as below it, indicating the model does not consistently overestimate or underestimate the groundwater levels provided by IDNR. The calibration near the proposed tunnel alignment shows surficial aquifer elevations are within approximately 0.3 to 1.5 feet of the measured elevations, which indicates reasonably good calibration.

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

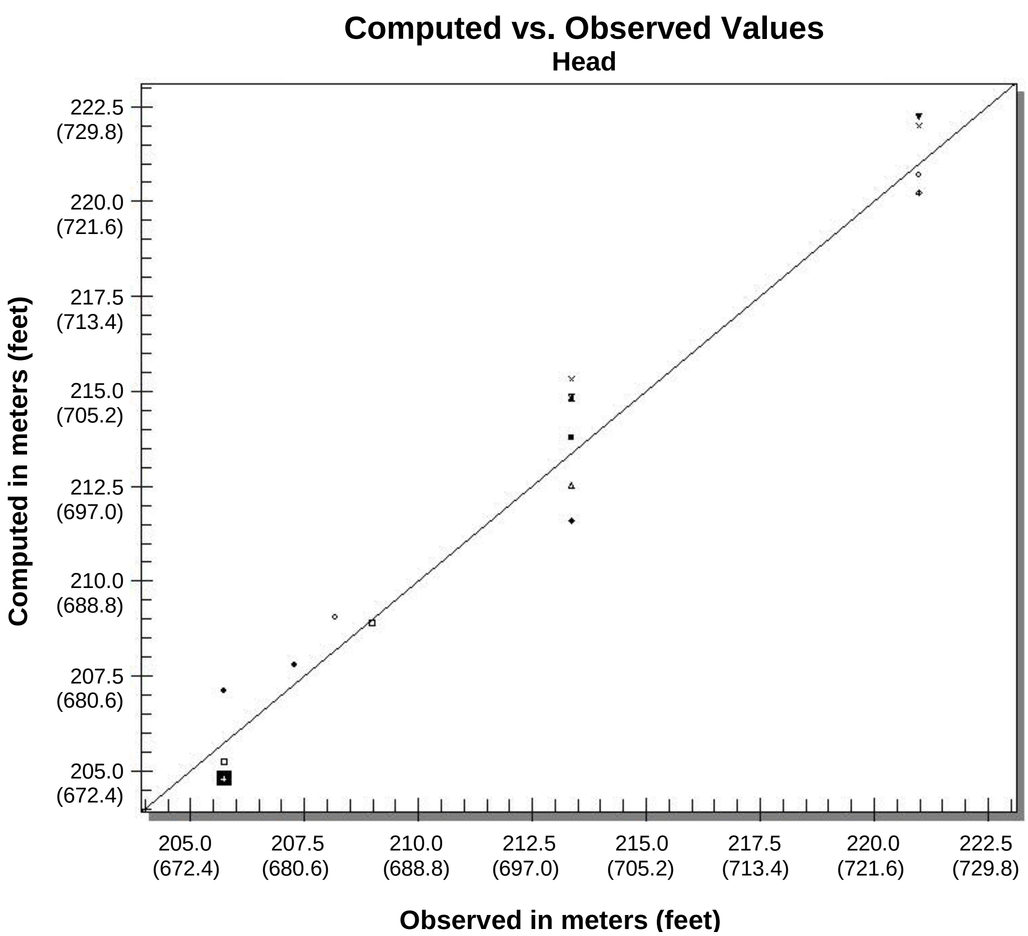

Figure 5.3 Calibration for Surficial Aquifer

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

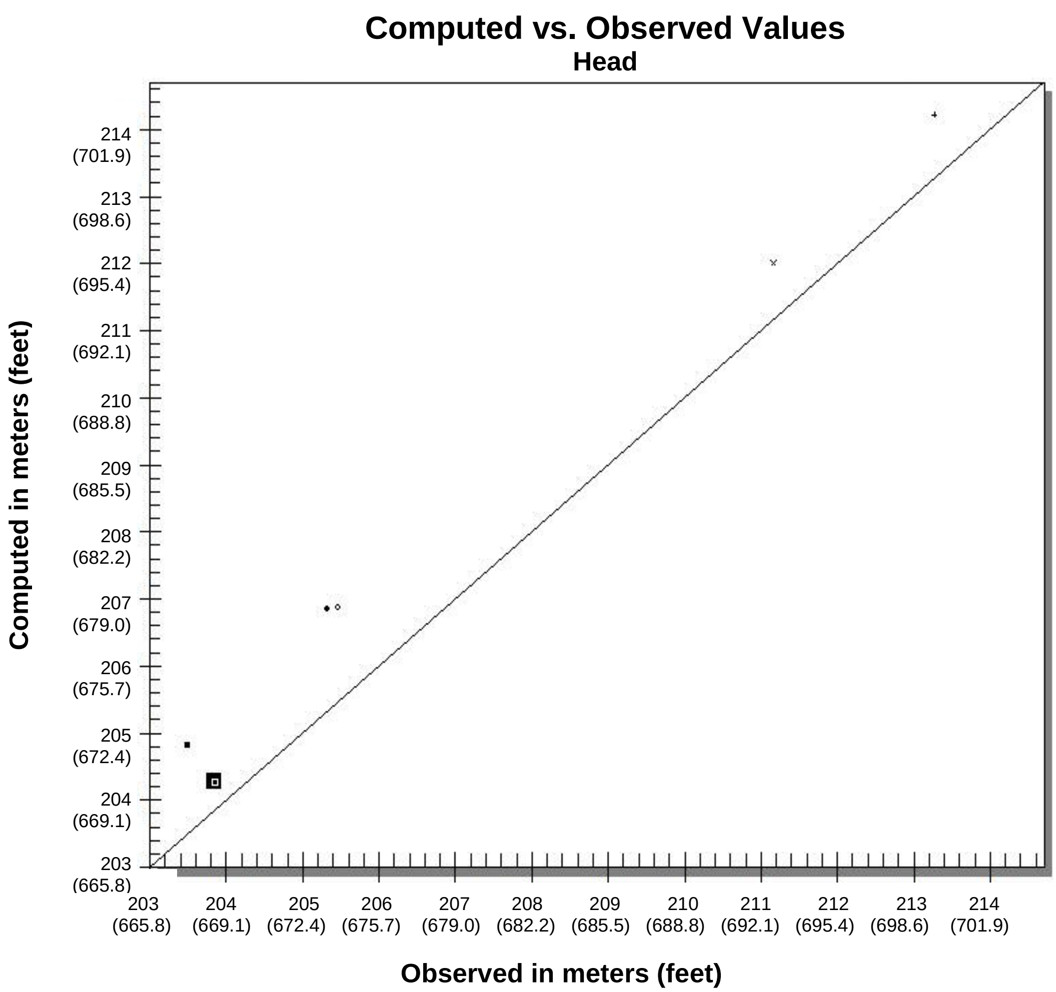

Figure 5.4 Calibration for Carbonate Aquifer

The modeled groundwater levels in the carbonate aquifer are generally higher than those measured in 2006 from the Phase 1A piezometers. Based on data from IDNR, the surficial aquifer groundwater levels are also higher than those measured in the carbonate aquifer. This indicates the model is trying to establish similar levels in the carbonate aquifer as in the surficial aquifer. The only way to prevent the aquifers from achieving similar levels in the steady-state model at the calibration points is to assign a low vertical hydraulic conductivity to reduce the hydraulic connection

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

between the aquifers. However, the Phase 1A piezometer data appears to indicate the carbonate groundwater levels fluctuate with the White River level. This indicates that there is "communication" between the surficial and carbonate aquifers. The carbonate groundwater levels recorded at Phase 1A piezometers B-1 and B-3 were compared to the stage of the White River recorded at the USGS gage near Raymond Street (Figure 5.5). Figure 5.6 shows the relationship between surface water and groundwater elevations at this location.

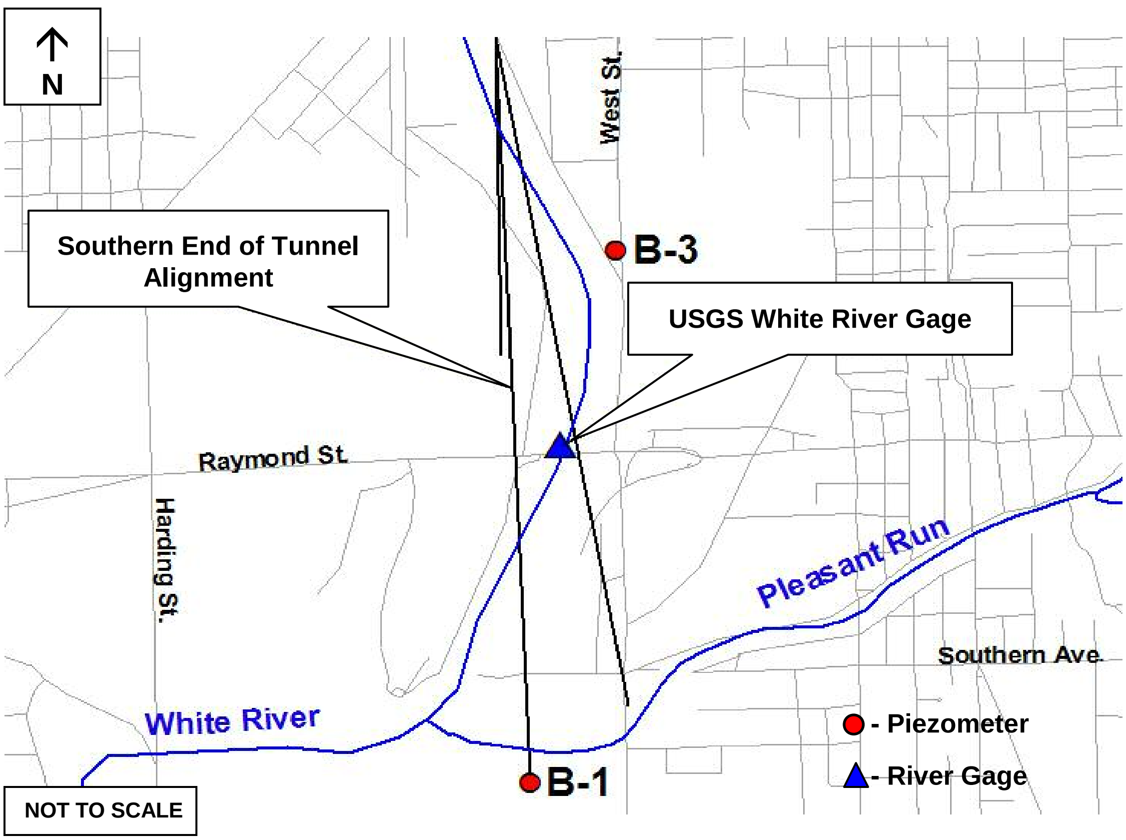

Figure 5.5 USGS Stream Gage and Phase 1A Piezometers

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5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

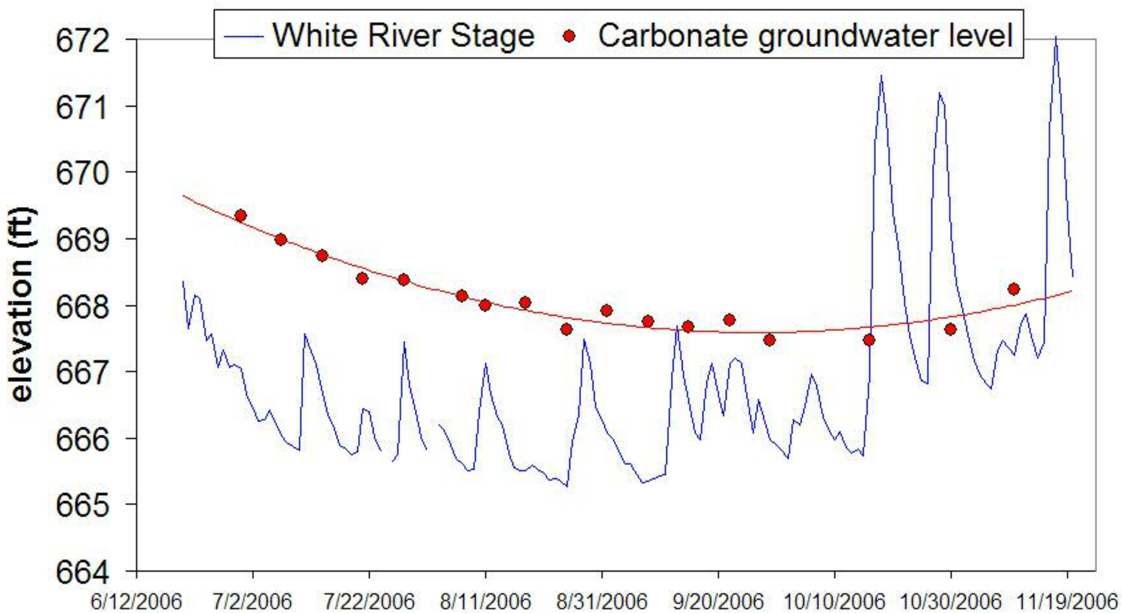

Figure 5.6 Trends for Surface Water and Groundwater Elevations Near the USGS White River at Indianapolis Stream Gage in 2006

It can be seen from Figure 5.6 that the trend in groundwater elevation tends to follow the same pattern as the trend in stream stage. This indicates that the White River and the shallow carbonate aquifer are hydraulically connected to some degree, and that the shallow carbonate aquifer and the surficial aquifer are also hydraulically connected. Assigning very low vertical hydraulic conductivities in the model in an attempt to achieve a better calibration for the carbonate groundwater levels would not support these findings. Instead, nested wells are recommended during future project phases to get simultaneous readings of the surficial and carbonate groundwater levels that can be used to improve the calibration.

Based on the available data, the calibration was completed to within 3 to 3.5 feet of existing field conditions. This is reasonably good considering the change in groundwater elevations across the entire model domain from the north to the south is

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

more than 100 feet. The standard deviation of the error for observation points is 3.35 feet. It is preferred that the ratio of standard deviation of error to the range in groundwater elevations across the model be less than 10 percent. With a range in groundwater elevations across the model of 100 feet, the ratio is 3.3 percent and within the 10 percent target. The range in groundwater elevations across the tunnel alignment is between 30 and 40 feet, and has a ratio of approximately 10 percent and is also considered within reason.

5.5 SENSITIVITY ANALYSIS

The sensitivity analysis of a groundwater model involves varying the model parameters to determine which parameters have the greatest effect on the model results, and to help show that different combinations of parameters do not result in a better calibration of the model.

A total of 22 sensitivity runs were performed by doubling or halving the major input parameters that were established during the calibration of the model. To see the effect of each input parameter on the model results, only one (1) parameter was varied at a time. The following sensitivity runs were performed:

- Sensitivity Run #1 – Double the recharge rate applied to the top of the model.
- Sensitivity Run #2 – Halve the recharge rate.
- Sensitivity Run #3 – Double the streambed conductance for all streams.
- Sensitivity Run #4 – Halve the streambed conductance.
- Sensitivity Run #5 – Double the horizontal hydraulic conductivity (Kh) for all zones within Layer 1.
- Sensitivity Run #6 – Halve the Kh for all zones within Layer 1.
- Sensitivity Run #7 – Double the vertical hydraulic conductivity (Kv) for all zones within Layer 1.
- Sensitivity Run #8 – Halve the Kv for all zones within Layer 1.
- Sensitivity Run #9 – Double the Kh for all zones within Layer 2.
- Sensitivity Run #10 – Halve the Kh for all zones within Layer 2.
- Sensitivity Run #11 – Double the Kv for all zones within Layer 2.

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

- Sensitivity Run #12 – Halve the Kv for all zones within Layer 2.
- Sensitivity Run #13 – Double the Kh for all zones within Layer 3.
- Sensitivity Run #14 – Halve the Kh for all zones within Layer 3.
- Sensitivity Run #15 – Double the Kv for all zones within Layer 3.
- Sensitivity Run #16 – Halve the Kv for all zones within Layer 3.
- Sensitivity Run #17 – Double the Kh for all zones within Layers 4 and 5.
- Sensitivity Run #18 – Halve the Kh for all zones within Layers 4 and 5.
- Sensitivity Run #19 – Double the Kv for all zones within Layers 4 and 5.
- Sensitivity Run #20 – Halve the Kv for all zones within Layers 4 and 5.
- Sensitivity Run #21 – Double the pumping rates for all layers.
- Sensitivity Run #22 – Halve the pumping rates for all layers.

As shown in Table 5.5 and described further in this section, the set of parameters determined from the calibration result in one of the best combinations of mean error, mean absolute error, root-mean squared error, and sum of residuals squared of all of the analyses. Overall, the sensitivity analyses provide a good level of confidence for the existing conditions model. Sensitivity Analysis #4, lowering the streambed conductances for all streams by half, resulted in slightly better calibration across the entire model. However, in the vicinity of the tunnel, the results for the calibrated model are slightly better. Therefore, the calibrated existing conditions model is considered to have the best set of input parameters based on the available data at the time of this evaluation.

The groundwater levels in the surficial aquifer (Layer 1) are most sensitive to the horizontal and vertical hydraulic conductivity of the various zones within the surficial aquifer. The groundwater levels in the surficial aquifer can be locally sensitive to variations in pumping rates, streambed conductance, precipitation recharge, and the horizontal hydraulic conductivity of the shale layer in the southern portion of the study area. The groundwater levels in the surficial aquifer are relatively insensitive to the horizontal and vertical hydraulic conductivity of the deeper carbonate and shale layers.

Table 5.5
Sensitivity Analysis (values are residuals in feet)

Sensitivity Run #				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Layer Number(s)				1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	4&5	4&5	4&5	4&5	1&2	1&2
Point	**Aquif**	**Meas (ft)**	**Calib (ft)**	**Rech x2**	**Rech /2**	**Cond x2**	**Cond /2**	**Kh x2**	**Kh /2**	**Kv x2**	**Kv /2**	**Kh x2**	**Kh /2**	**Kv x2**	**Kv /2**	**Kh x2**	**Kh /2**	**Kv x2**	**Kv /2**	**Kh x2**	**Kh /2**	**Kv x2**	**Kv /2**	**Pump x2**	**Pump /2**
MA35	surf	685.6	-0.3	0.7	-0.7	3.0	-2.3	1.6	-3.6	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-7.2	3.6
MA36	surf	680.1	1.6	2.3	1.3	5.2	-0.7	3.0	0.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	-3.9	5.2
MA37	surf	683.0	3.0	3.3	3.0	3.3	2.3	2.6	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.3	3.3
idnr02c	surf	725.0	3.3	3.9	3.0	3.6	3.3	3.6	3.0	3.3	3.3	3.3	3.3	3.3	3.3	2.6	3.6	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.6
idnr02d	surf	725.0	-2.6	-1.0	-3.3	-2.0	-3.0	-2.0	-3.6	-2.6	-2.6	-2.6	-2.3	-2.6	-2.6	-3.9	-1.6	-2.6	-2.6	-3.0	-2.3	-2.6	-2.6	-3.6	-1.6
idnr02i	surf	725.0	4.3	4.6	3.9	4.3	3.9	3.9	4.3	4.3	4.3	4.3	4.3	4.3	4.3	3.9	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
idnr02n	surf	700.0	4.9	5.2	4.6	4.9	4.9	4.6	5.2	4.9	4.9	4.9	4.9	4.9	4.9	4.6	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
idnr02m	surf	700.0	4.9	5.6	4.3	5.2	4.3	4.9	4.6	4.9	4.9	4.9	4.9	4.9	4.9	4.6	4.9	4.9	4.9	4.6	4.9	4.9	4.9	3.9	5.2
idnr02l	surf	700.0	-2.6	-1.6	-3.0	-1.6	-3.0	-3.6	-1.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6
idnr02k	surf	700.0	-5.9	-5.6	-5.9	-5.9	-5.6	-5.9	-5.6	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9	-5.6	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9
idnr02j	surf	725.0	-2.3	1.3	-4.3	-2.3	-2.3	-2.0	-3.3	-5.6	0.0	-2.6	-2.3	-2.3	-2.3	-2.6	-2.0	-2.3	-2.3	-2.6	-2.3	-2.3	-2.3	-2.3	-2.3
idnr02g	surf	700.0	1.3	16.4	-5.6	1.6	1.0	-1.3	3.3	-3.0	7.9	1.0	1.6	1.3	1.3	0.3	2.3	1.3	1.3	0.7	2.0	1.3	1.3	1.0	1.6
idnr02f	surf	675.0	-1.6	11.2	-7.5	-1.3	-2.0	-1.0	-3.0	-4.6	4.9	-2.3	-1.0	-1.6	-1.6	-3.0	-0.3	-1.6	-1.6	-3.0	-0.3	-1.6	-1.6	-5.2	0.3
idnr02e	surf	675.0	4.6	4.9	4.3	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.3	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.3	4.6
idnr02a	surf	725.0	-1.0	80.4	-62.3	-1.0	-1.0	-8.9	1.3	-50.5	42.3	-3.6	1.0	-1.0	-1.0	-6.2	3.0	-1.0	-1.0	-7.5	4.3	-1.0	-1.0	-1.6	-0.7
idnr02o	surf	700.0	6.6	6.6	6.6	6.6	6.6	6.9	6.2	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.9	6.9
idnr02p	surf	675.0	-3.0	-3.0	-3.3	-3.3	-3.0	-2.0	-3.9	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.3	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-4.3	-2.3
B-1	carb	667.5	4.3	4.6	4.3	3.9	4.9	4.9	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.6	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.6
B-3	carb	668.7	1.3	1.6	1.3	1.3	1.6	2.3	1.0	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	0.7	2.0
B-6	carb	673.5	4.9	5.2	4.9	5.6	4.3	5.2	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	5.2	4.9	4.9	4.9	4.9	4.9	4.9	4.3	5.6
B-10	carb	674.0	4.6	4.9	4.6	4.9	3.9	5.9	3.0	4.6	4.6	4.6	4.6	4.6	4.6	4.9	4.6	4.6	4.6	4.6	4.6	4.6	4.6	2.6	6.2
B-15	carb	692.7	3.0	3.0	2.6	3.6	1.3	2.3	3.0	3.0	2.6	2.6	3.0	3.0	2.6	2.6	3.0	3.0	2.6	2.6	3.0	3.0	3.0	1.6	3.3
B-17	carb	699.6	3.3	3.3	3.0	3.0	3.3	3.3	3.0	3.3	3.3	3.3	3.3	3.3	3.3	3.0	3.3	3.0	3.3	3.3	3.0	3.3	3.3	3.0	3.3
Mean Error (ft)			*1.6*	*6.9*	*-2.0*	*2.0*	*1.3*	*1.3*	*1.3*	*-1.0*	*4.3*	*1.3*	*1.6*	*1.6*	*1.6*	*1.0*	*2.0*	*1.6*	*1.6*	*1.3*	*2.0*	*1.6*	*1.6*	*0.3*	*2.3*
Mean Absolute Error (ft)			*3.6*	*8.2*	*6.6*	*3.9*	*3.3*	*3.9*	*3.6*	*5.9*	*5.6*	*3.6*	*3.3*	*3.6*	*3.6*	*3.6*	*3.6*	*3.6*	*3.6*	*3.9*	*3.6*	*3.6*	*3.6*	*3.9*	*3.9*
RMSE (ft)			*3.6*	*17.7*	*13.8*	*3.9*	*3.6*	*4.3*	*3.6*	*11.2*	*9.8*	*3.6*	*3.6*	*3.6*	*3.6*	*3.9*	*3.6*	*3.6*	*3.6*	*3.9*	*3.6*	*3.6*	*3.6*	*3.9*	*3.9*
Sum R^2 (ft^2)			*304*	*7,160*	*4,268*	*353*	*284*	*412*	*320*	*2,913*	*2,171*	*320*	*302*	*304*	*302*	*342*	*315*	*304*	*302*	*366*	*321*	*304*	*304*	*371*	*379*

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

The groundwater heads in the carbonate aquifer are somewhat sensitive to the horizontal hydraulic conductivity of the surficial aquifer. Locally, for those observation points closest to the wells, the heads in the carbonate aquifer are sensitive to the pumping rates. However, the carbonate aquifer heads are relatively insensitive to the other input parameters for the ranges evaluated. This evaluation indicates the most significant effect on the groundwater levels in the carbonate aquifer are the groundwater levels in the surficial aquifer. This is especially true in areas where the carbonate surface is mostly weathered and is in direct contact with the permeable alluvium and outwash material within the surficial aquifer. In these areas, the groundwater levels of both aquifers are similar as the aquifers are believed to be hydraulically connected.

5.6 EXISTING CONDITIONS MODEL

5.6.1 Existing Conditions Model Parameters

This section graphically summarizes the existing conditions model parameters resulting from the calibration and the sensitivity analysis. Figures 5.7 through 5.11 illustrate the input parameters for the existing conditions model for hydraulic conductivity and precipitation recharge.

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

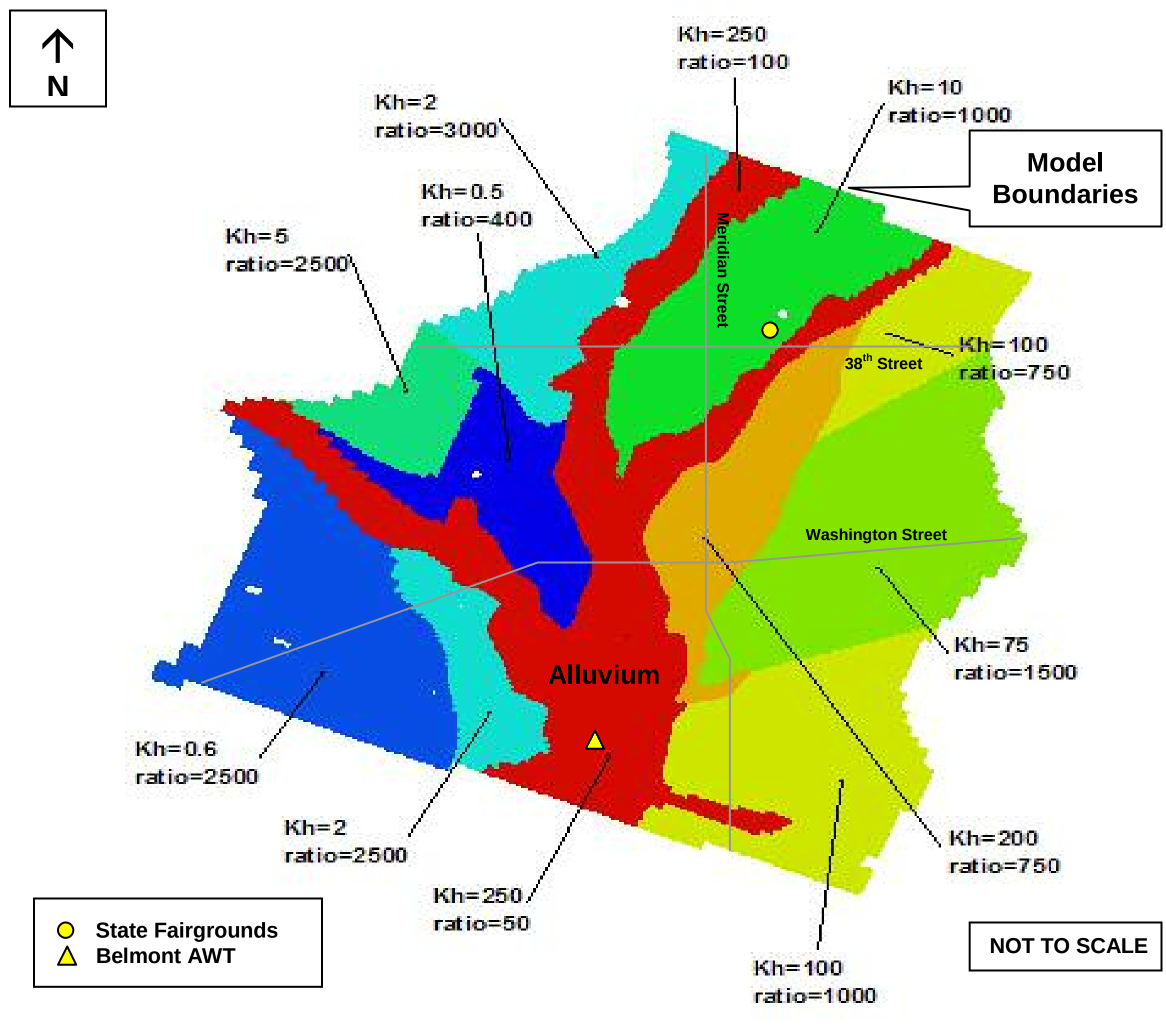

Figure 5.7 Layer 1 Horizontal Hydraulic Conductivity (ft/day) and Horizontal-to-Vertical Hydraulic Conductivity Ratio

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5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

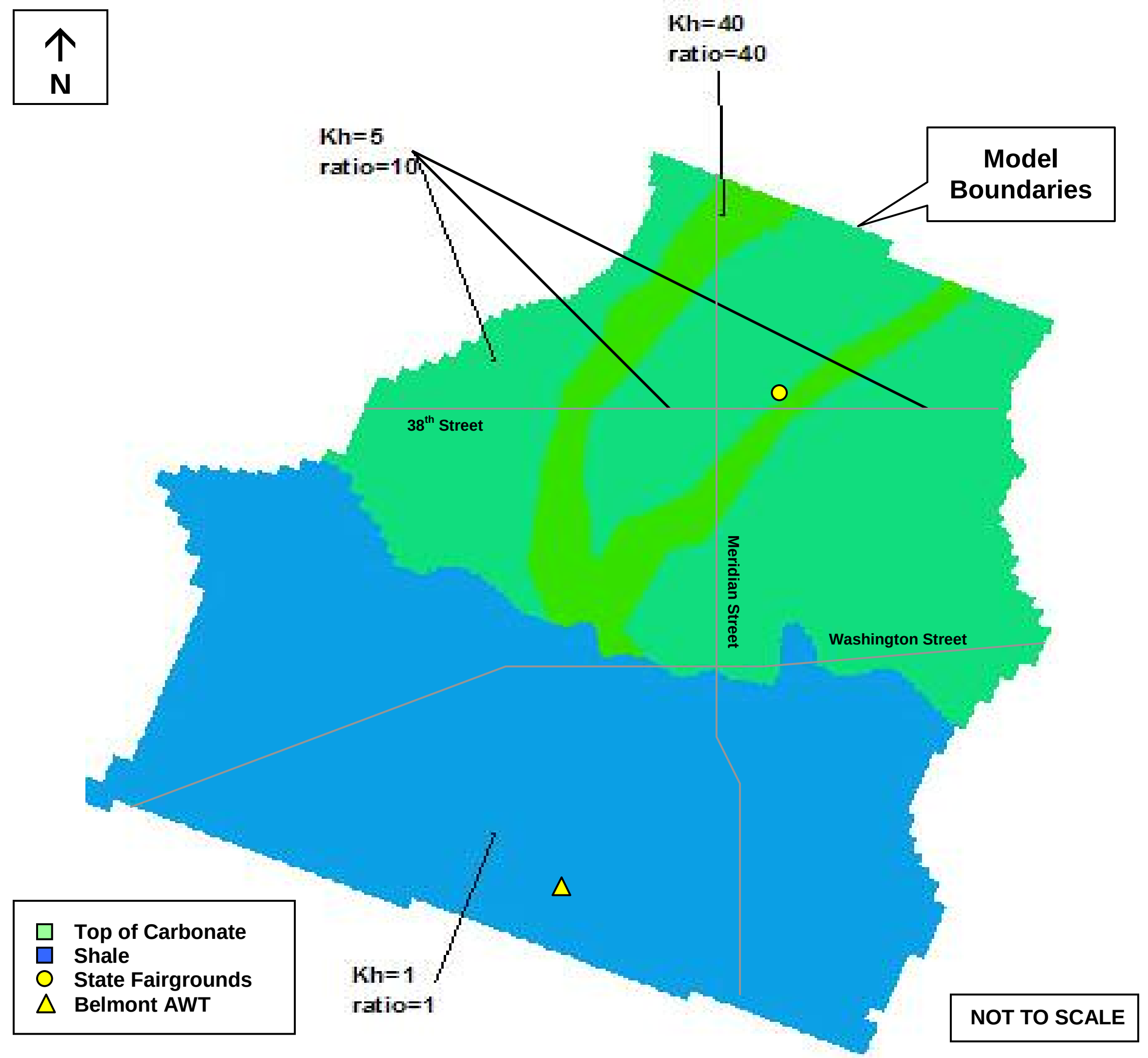

Figure 5.8 Layer 2 Horizontal Hydraulic Conductivity (ft/day) and Horizontal-to-Vertical Hydraulic Conductivity Ratio

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

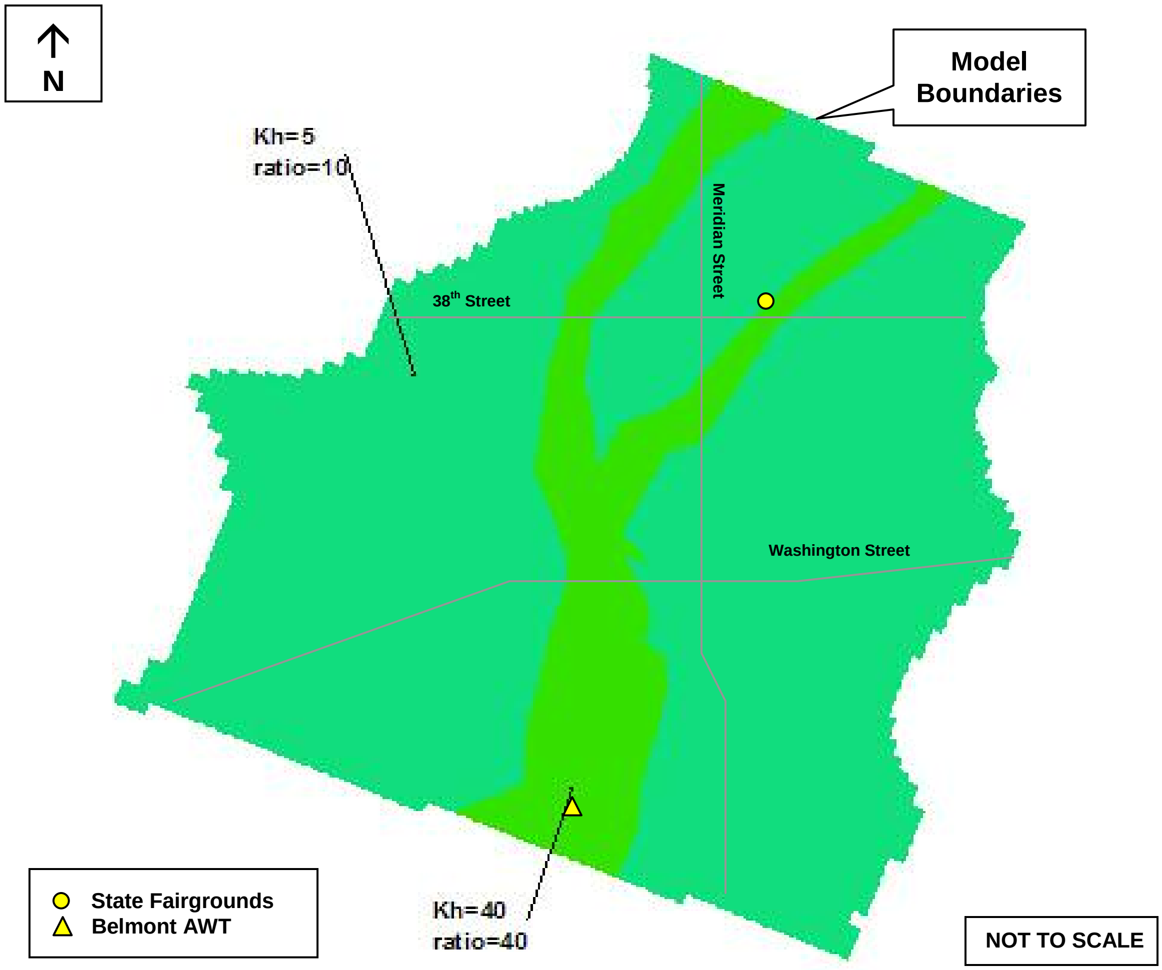

Figure 5.9 Layer 3 Horizontal Hydraulic Conductivity (ft/day) and Horizontal-to-Vertical Hydraulic Conductivity Ratio

BLACK & VEATCH Corporation

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

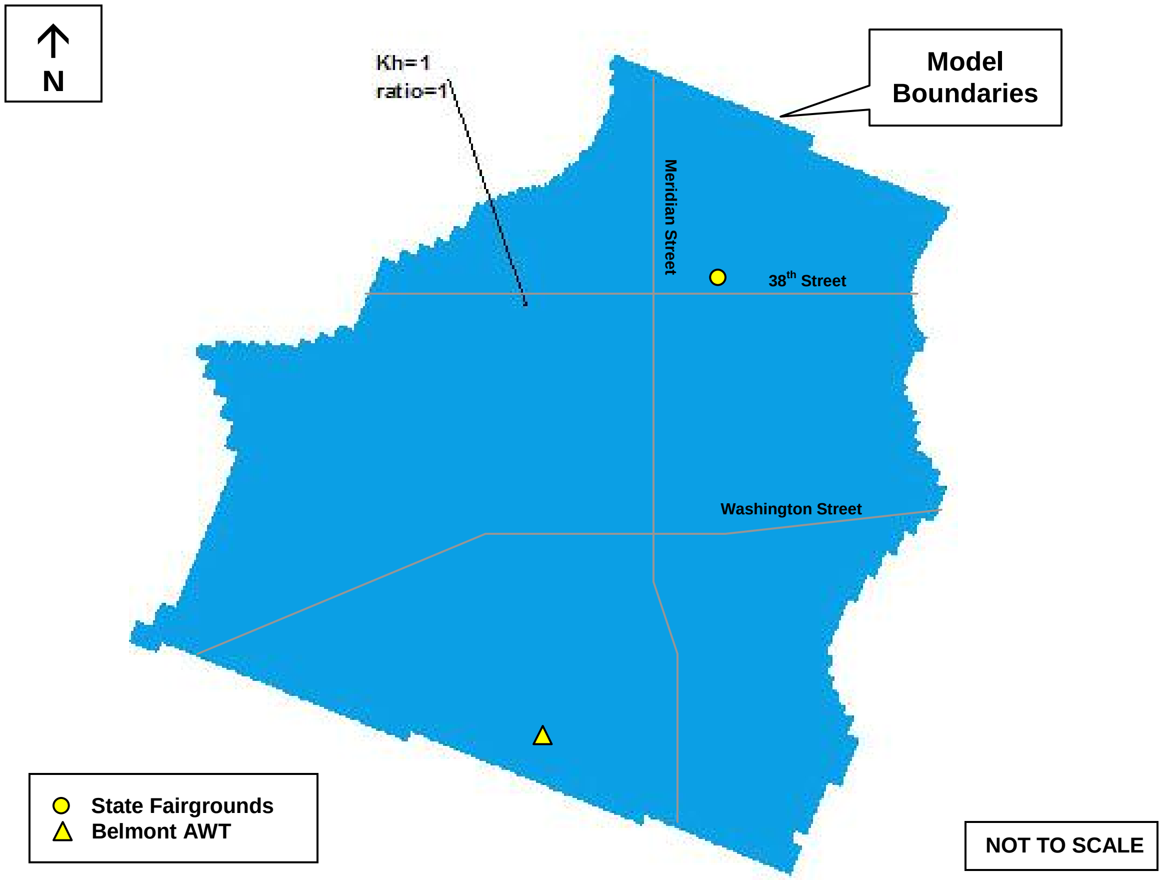

Figure 5.10 Layer 4 and 5 Horizontal Hydraulic Conductivity (ft/day) and Horizontal-to-Vertical Hydraulic Conductivity Ratio

Note: Layers 4 and 5 are greater than 50 feet below the top of the carbonate aquifer. Published information indicates the upper portion of the carbonate is the most permeable. No known pumping tests have been performed with a production well open only to the deep carbonate aquifer, so the estimate of K=1 ft/day was based on estimates of hydraulic conductivity from packer tests that were performed during the Phase 1A Geotechnical Investigation.

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5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

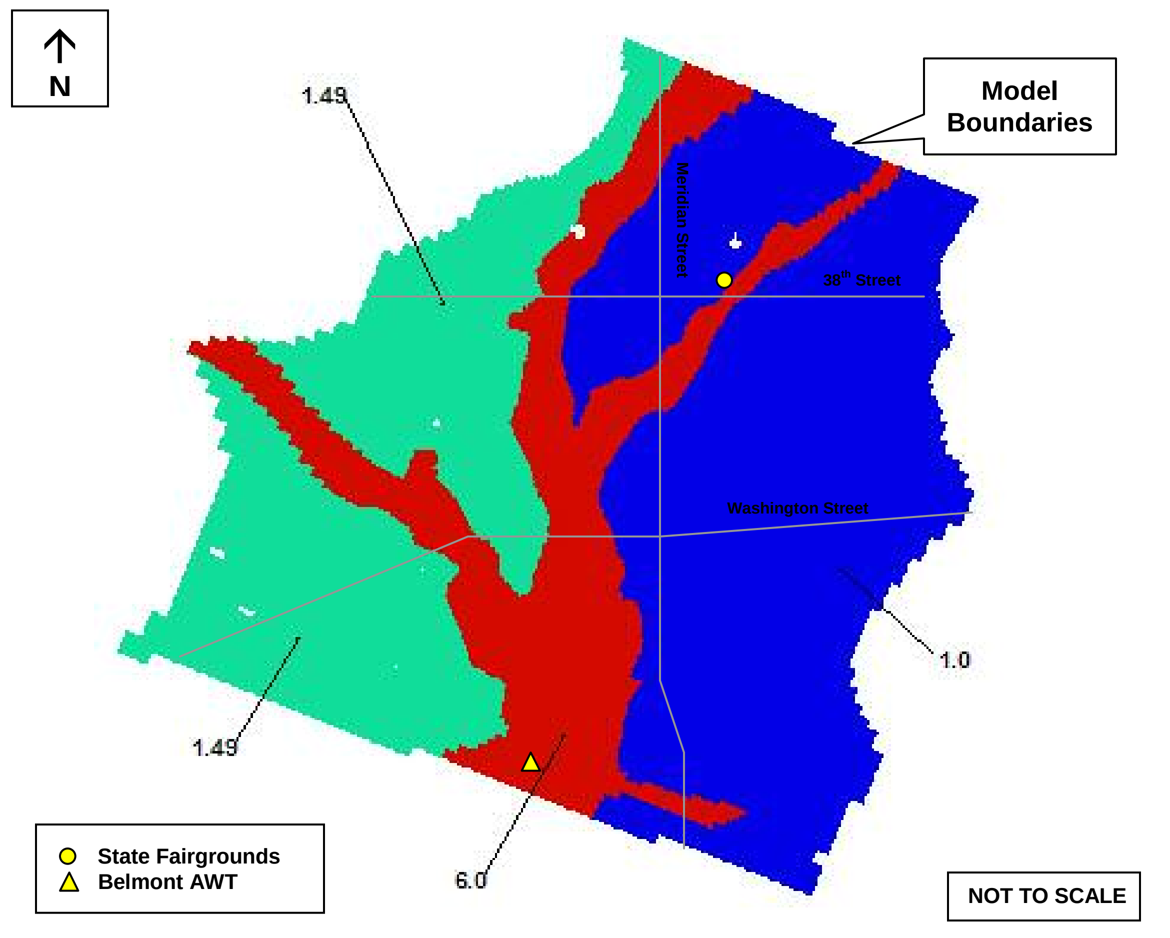

Figure 5.11 Precipitation Recharge (in/yr)

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

5.6.2 Groundwater Flow Budget

The groundwater budget from the calibrated existing conditions groundwater model is shown on Figure 5.12 and summarized below:

<u>*Net Flows Into (+) or Out of (-) the Groundwater System*</u>

Boundaries = +6,928 gpm
All Streams = +5,110 gpm
Recharge = +8,722 gpm
Wells = -20,760 gpm

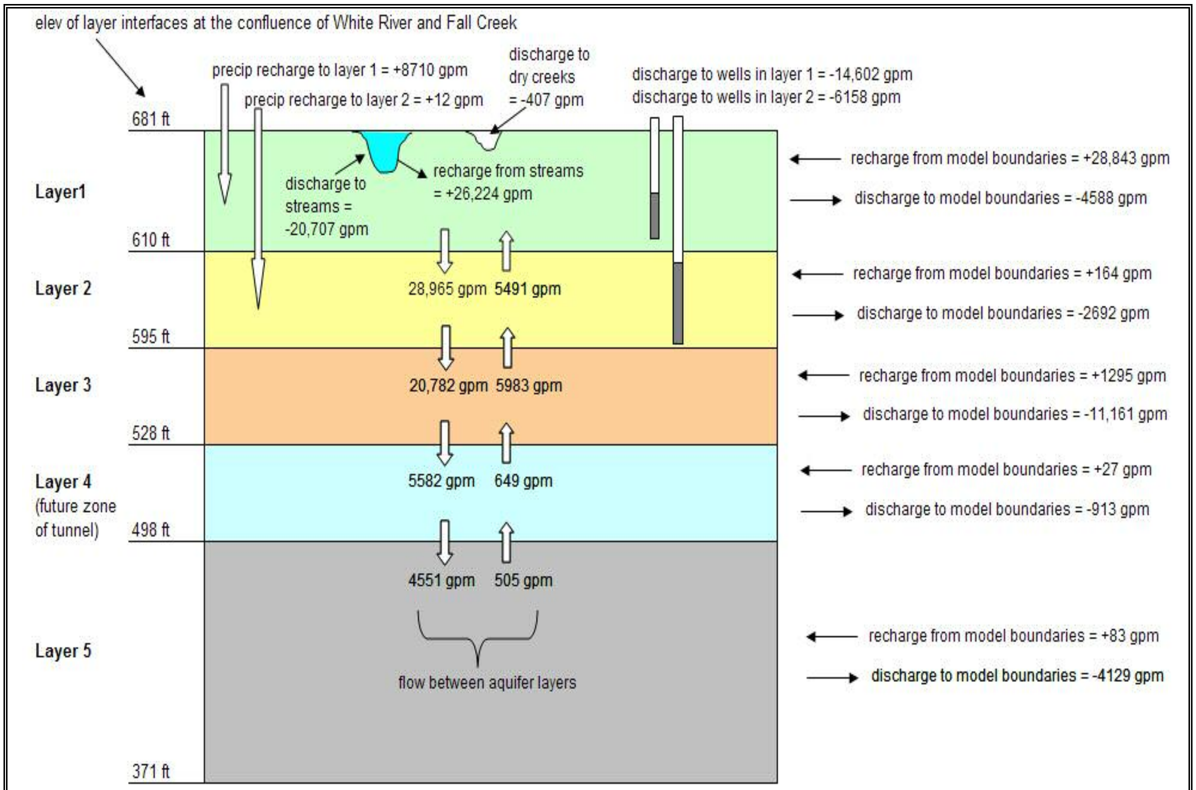

Figure 5.12 Existing Conditions Model – Groundwater Budget

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5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

Streams, boundaries, and recharge provide net inflow for the groundwater system, and wells provide net outflow from the groundwater system. Evapotranspiration was incorporated into the recharge estimates for the model. Published information (Smith, 1983) indicates that the groundwater in the region generally discharges to streams, but the interaction between groundwater and surface water is highly uncertain for most areas. As previously discussed in Section 3, groundwater probably discharged to the major streams in the Indianapolis area prior to development, but wells and dams have reversed the direction of flow from the streams into the aquifer in many places. Available literature indicates that streams discharge to the aquifer behind dams along White River where the surface water is impounded to an elevation higher than the groundwater levels adjacent to the river (ATEC, 1995). Pumping from high capacity wells along the White River and Fall Creek also induce streamflow into the aquifer. Due to the amount of pumping and number of dams, the calibrated model shows a net recharge of streamflow into the aquifer in the study area. A review of the model results confirms recharge of streamflow into the aquifer behind dams and near the wellfields. Review of available literature also indicated that seepage from the Indianapolis Water Supply Canal into the aquifer can be as high as 21 cubic feet per second (cfs) (Meyer, 1979). The calibrated model shows a seepage rate of approximately 13 cfs from the Canal, which is reasonably close to the estimated average value.

In most other areas, the model results indicate a discharge of groundwater to the streams. The carbonate groundwater levels measured at Phase 1A monitoring wells B-1 and B-3 (adjacent to the White River) are slightly higher than the stream stage, indicating the groundwater discharges to the White River at this location (USGS, 2006). The calibrated existing conditions groundwater model results also confirm that the groundwater discharges to the river at this location.

The groundwater contours for the existing conditions model are shown for the surficial aquifer on Figure 5.13, and for the upper carbonate aquifer on Figure 5.14. Visual comparison to available data and mapping for the surficial and carbonate aquifers shows that the model is creating a similar pattern for the groundwater contours, which indicates a well calibrated model.

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

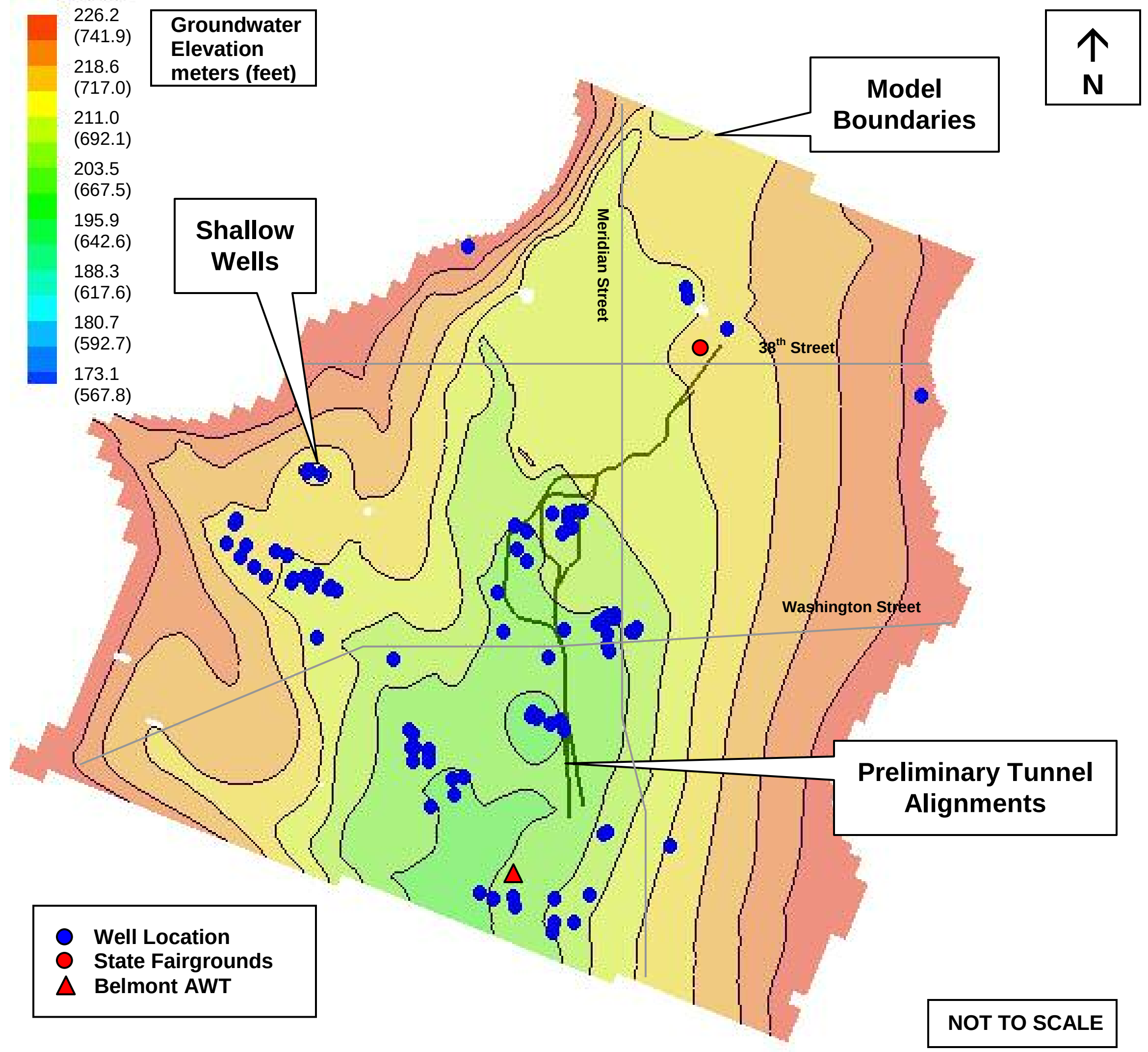

Figure 5.13 Existing Conditions Groundwater Contours for Surficial Aquifer (Layer 1)

5. MODEL CALIBRATION AND SENSITIVITY ANALYSES

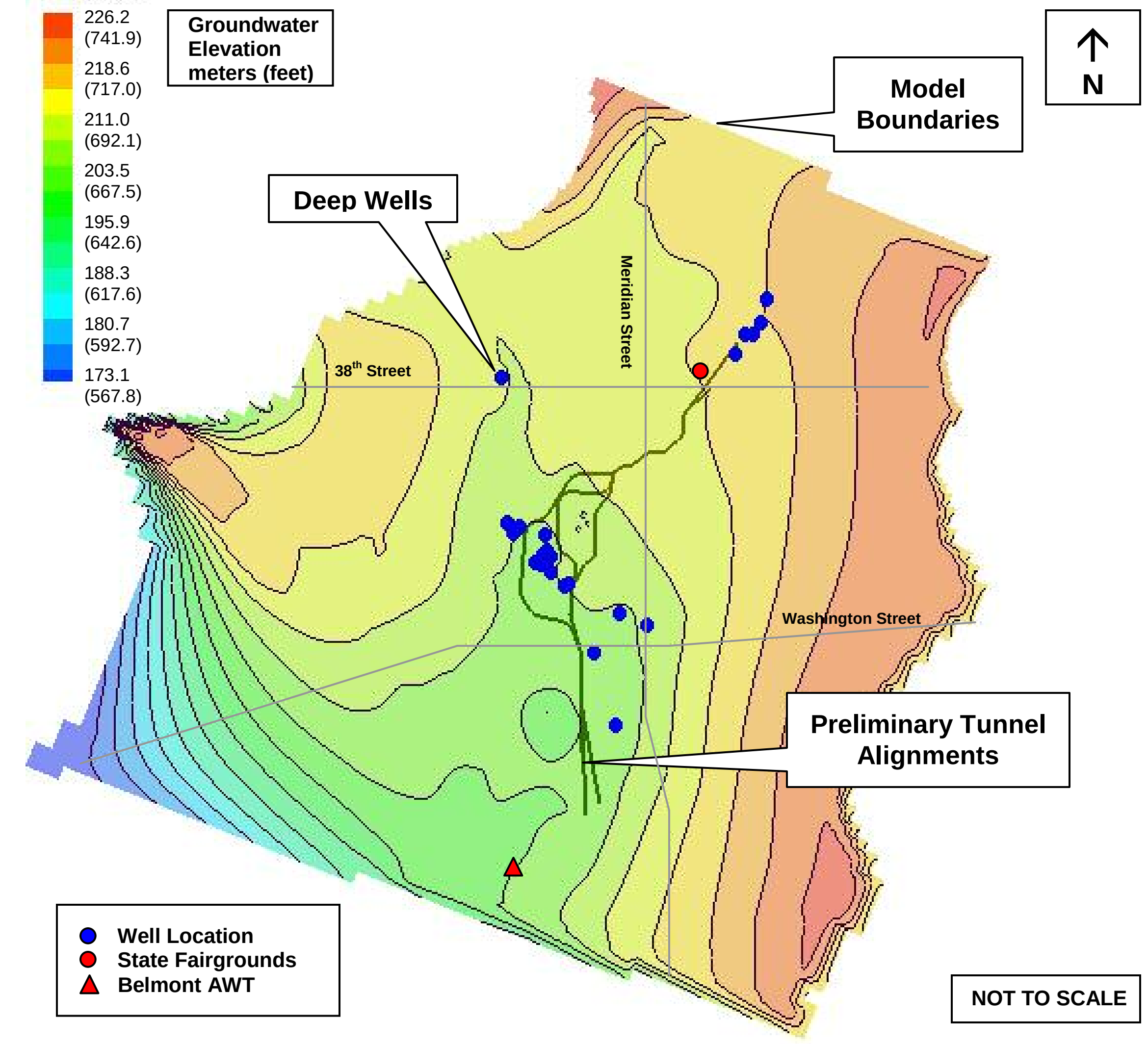

Figure 5.14 Existing Conditions Groundwater Contours for Upper Carbonate Aquifer (Layer 2)